

A search for magnetic fields in cool sdB stars*

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Hot cluster Horizontal Branch (HB) stars and field subdwarf B (sdB) stars are core helium burning stars that exhibit abundance anomalies that are believed to be due to atomic diffusion. Diffusion can be effective in these stars because they are slowly rotating. In particular, the slow rotation of the hot HB stars ($T_{\text{eff}} > 11,000$ K), which show abundance anomalies, contrasts with the fast rotation of the cool HB stars, where the observed abundances are consistent with those of red giants belonging to the same cluster. The reason why sdB stars and hot HB stars are rotating slowly is unknown. In order to assess the possible role of magnetic fields on abundances and rotation, we investigated the occurrence of such fields in sdB stars with $T_{\text{eff}} < 30,000$ K, whose temperatures overlap with those of the hot HB stars. We conclude that large-scale organised magnetic fields of kG order are not generally present in these stars but at the achieved accuracy, the possibility that they have fields of a few hundred Gauss remains open. We report the marginal detection of such a field in SB 290; further observations are needed to confirm it.

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1 Introduction

Horizontal branch (HB) stars of clusters and their field equivalents, the subdwarf B and O (sdB and sdO) stars, represent a challenge for stellar evolution theory. While they are all known to burn He in their centre, the evolutionary scenario leading to sdB and sdO stars is not well established. It is not well understood either why there are such relative differences as observed in the number of blue or extremely blue HB stars from one cluster to the other. While metallicity is part of the explanation, it cannot account for the diversity of HB branch morphologies observed. Reviews of typical characteristics of HB stars in clusters are presented in the works of Moehler (2001) and Moehler & Sweigart (2006). In those globular clusters where HB stars with $T_{\text{eff}} > 11,000$ K are present, they have been observed to have 180 metal abundances very different from those of the red giant (RG) branch stars of the same clusters, while the HB stars with $T_{\text{eff}} < 11,000$ K have the same abundances as RG branch stars. For instance, 6 of the 7 HB stars of M15 with $T_{\text{eff}} > 11,000$ K observed by Behr et al. (1999) (see their Fig. [1]) have $[\text{Fe}/\text{H}]$ larger by a factor of 50 than all cooler HB stars and the RG branch stars.

Similar results were obtained in many other clusters (Behr et al. 2000a; Behr 2003; Moehler et al. 2000; Fabbian et al. 2005; Pace et al. 2006). Furthermore, the hotter HB stars rotate more slowly than the cooler ones that show no abundance anomalies (Behr et al. 2000a, 2000b; Recio-Blanco et al. 2002)

The abundance anomalies in those hot HB stars are believed to be caused by atomic diffusion, radiative accelerations leading for instance to the observed Fe overabundances (Michaud et al. 2008). The link with atomic diffusion is strengthened by the observed slow rotation, a feature which is also a characteristic of Ap and HgMn stars and is required to allow the slow diffusion processes to be effective. Similar statements can be made for the sdB stars, for which both abundance anomalies of heavy elements associated with diffusion processes (Geier et al. 2010; Michaud et al. 2011) and very slow rotation velocities are usually the norm (Edelmann 2003). However the reason why very blue HB and sdB stars rotate slowly is not known. Some suggestions have been made but are not generally accepted. Magnetic fields are believed to be responsible for the slow rotation of Ap stars, but the origin of the slow rotation of HgMn stars is also unknown. Could the presence of a magnetic field differentiate slowly rotating blue HB stars with $T_{\text{eff}} > 11,000$ K and abundance anomalies from the red HB stars with the same composition as the RG stars? Most sdBs and sdOs are also believed to have abundance anomalies caused by atomic diffusion. Gravitational settling of He

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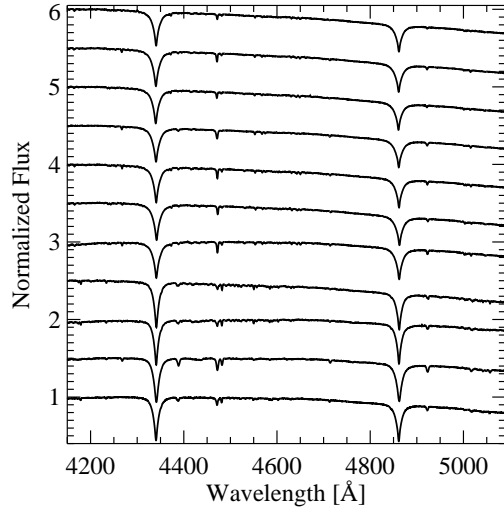


Fig. 1 Stokes *I* spectra of the ten sdB stars and Feige 86 in the spectral region from 4200 to 5000 Å. From the bottom to the top we present: Feige 86, EC 15327-1341, EC 19490-7708, EC 19579-4259, GD 1110, LB 1516, LB 1559, SB 290, SB 410, SB 459, and SB 815. Note the similarity between most sdB spectra and the spectrum of Feige 86.

is important in most of them except for some of the sdOs where, in some cases, He is more abundant than H.

In the past, magnetic fields of up to 1450 G were detected at significance levels ranging from 4 to 12 σ in four sdB and two sdO stars by O'Toole et al. (2005). A variable magnetic field (from ~ 0 to 10 kG) was observed by Valyavin et al. (2006) in the sdO star Feige 34. Magnetic fields of -1680 G in an sdO star and varying between -1300 and 1750 G in the sdOB star Feige 66 were observed by Elkin (1996). Magnetic fields have now been observed in all sdO and sdB stars in which they were looked for with an error bar lower than 1000 G. Only upper limits had been observed for Feige 86 and one sdO by Borra et al. (1983) but the error bars are compatible with the more recent observations. All these stars have effective temperatures close to or greater than 30,000 K. It then appears likely that magnetic fields of kG order are present in most if not all sdO and hot sdB stars. To our knowledge, there has been no attempt so far to detect magnetic fields in cool sdBs or in HB stars of globular clusters. While sdOs, sdBs and hot HB stars probably do not all have exactly the same evolutionary scenario, the fact that they all burn He in their centre and the presence of diffusion-caused anomalies suggests that they are strongly linked. It seems plausible that magnetic fields may be an important factor for all of them. Establishing the presence or absence of such fields will provide important clues about their potential role in slowing these stars down. This could for instance be done though magnetic fields forcing iso-rotation during their preceding evolution, as magnetic

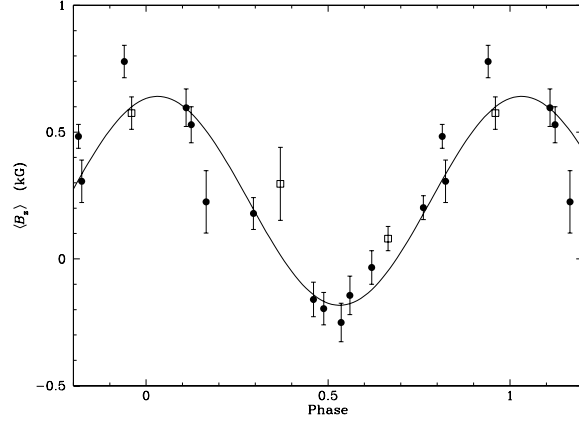


Fig. 2 The FORS 2 measurements of the mean longitudinal magnetic field of the Ap star HD 142070 that are reported here (*open squares*) are plotted together with the CASPEC measurements of Mathys et al. (in preparation; *dots*) against phase, assuming a rotation period of 3^d37211 and a phase origin MJD₀ = 49877.7. The solid curve is the best fit of the data by a sinusoid.

fields have been suggested to do for the solar radiative interior (Charbonneau & MacGregor 1993). To test the hypothesis that the observed abundance anomalies of sdOs, sdBs and hot HB stars reflect the presence of magnetic fields in these stars, we conducted a systematic search for magnetic fields in field sdB stars with $T_{\text{eff}} < 30,000$ K.

2 Observations and magnetic field measurements

We obtained FORS 2 longitudinal magnetic field measurements of ten sdB stars over three consecutive nights, from 28 to 31 August 2009. Measurements of each star were based on a sequence of observations with the following positions of the retarder waveplate: $+45^\circ$, -45° , $+45^\circ$, -45° , etc. We used grism 600B and a slit width of $0''.4$ to achieve a spectral resolving power of $R \approx 2000$. The observations were performed using the readout mode (100 kHz, high, 1 x 1). Most of the stars in our sample were observed on each night to check the magnetic field variability. More details on the observing technique with FORS 1 can be found elsewhere (e.g., Hubrig et al. 2004a, 2004b, and references therein). The mean longitudinal magnetic field, $\langle B_z \rangle$, was derived using

$$\frac{V}{I} = -\frac{g_{\text{eff}} e \lambda^2}{4\pi m_e c^2} \frac{1}{I} \frac{dI}{d\lambda} \langle B_z \rangle, \quad (1)$$

where V is the Stokes parameter that measures the circular polarisation, I is the intensity in the unpolarised spectrum, g_{eff} is the effective Landé factor, e is the electron charge, λ is the wavelength, m_e the electron mass, c the speed of light, and $dI/d\lambda$ is the derivative of Stokes I .

Table 1 Longitudinal magnetic field measurements of ten sdB stars.

Object name	MJD	$\langle B_z \rangle^{\text{all}}$ [G]	$\overline{\langle B_z \rangle^{\text{all}}}$ [G]	$(\chi^2/n)^{\text{all}}$	$\langle B_z \rangle^{\text{hyd}}$ [G]	$\overline{\langle B_z \rangle^{\text{hyd}}}$ [G]	$(\chi^2/n)^{\text{hyd}}$
HD 142070	55071.9949	296±144	376	29.2	311±228	312	6.0
HD 142070	55072.9935	80± 48			104± 90		
HD 142070	55073.9859	575± 64			431±112		
EC15327	55072.0182	216±152	136	0.9	232±166	140	0.7
EC15327	55073.0209	57±124			65±142		
EC15327	55074.0071	−76±128			−31±146		
EC19490	55072.0864	−118±132	103	0.6	−124±144	140	0.9
EC19490	55073.0881	112±125			162±140		
EC19490	55074.0776	−77±147			−133±152		
EC19579	55072.0443	322±120	215	3.3	317±133	226	3.0
EC19579	55073.0485	30± 65			32±124		
EC19579	55074.0300	188±118			229±126		
GD1110	55072.2234	279±180	249	1.7	294±205	355	2.7
GD1110	55073.1538	216±211			408±220		
LB1516	55072.1442	−370±182			−373±212		
LB1516	55073.2173	−433±185	402	4.8	−526±206	455	4.8
LB1559	55072.2705	−159±202			−256±220		
LB1559	55073.3097	63±178			80±202		
LB1559	55074.3159	−349±208	224	1.2	−441±221	298	1.8
SB290	55072.3814	56±200			118±208		
SB290	55073.2561	−639±188			−856±209		
SB290	55074.2236	−211±135	389	4.7	−401±148	549	8.1
SB410	55072.3089	−457±182			−508±210		
SB410	55073.3526	−149±184			−122±208		
SB459	55072.3478	48±180	290	2.1	144±198	321	2.1
SB459	55073.3965	−453±204			−486±230		
SB459	55074.3839	215±188			229±192		
SB815	55072.1807	−97±204	261	1.6	−204±212	352	2.3
SB815	55072.4024	417±208			563±242		
SB815	55073.2783	−178±184			−216±208		
SB815	55074.2745	242±210			301±224		

The longitudinal magnetic field was measured in two ways: using only the absorption hydrogen Balmer lines or using the entire spectrum including all available absorption lines. In Fig. 1 we present FORS 2 integral spectra for all observed targets together with the well-studied Pop II halo B-type star Feige 86 with $T_{\text{eff}} = 16\,430\text{ K}$, in which we searched for a magnetic field in May 2011. As we mention above, only upper limits have been obtained for Feige 86 by Borra et al. (1983). It is however possible that Feige 86 exhibits more similarity with HgMn stars than with sdB stars, as it shows He and Hg isotopic anomalies (Hubrig et al. 2009).

Our measurements of magnetic fields in ten sdB stars together with the observations of the classical Ap star HD 142070 (used as a standard star) are shown in Table 1. The first two columns list the object name and the modified Julian date of mid-exposure, followed by the measured longitudinal magnetic field $\langle B_z \rangle^{\text{all}}$ using the whole spectrum. In columns 4 and 5 we give the rms field $\overline{\langle B_z \rangle^{\text{all}}}$ and the reduced χ^2 . Columns 6 to 8 list $\langle B_z \rangle^{\text{hyd}}$, $\overline{\langle B_z \rangle^{\text{hyd}}}$, and $(\chi^2/n)^{\text{hyd}}$ for the measurements using hydrogen lines.

In order to minimize the risk of apparent non-detection in some of the targets of our sample, due to fortuitous null observations of the longitudinal field close to the phases where it reverses its sign, stars were observed at two to four different epochs. The rms field is defined as:

$$\overline{\langle B_z \rangle} = \left(\frac{1}{n} \sum_{i=1}^n \langle B_z \rangle_i^2 \right)^{1/2}, \quad (2)$$

and the reduced χ^2 as

$$\chi^2/n = \frac{1}{n} \sum_{i=1}^n \left(\frac{\langle B_z \rangle_i}{\sigma_i} \right)^2, \quad (3)$$

where n is the number of measurements of the considered star, $\langle B_z \rangle_i$ is the i -th such measurement and σ_i is its uncertainty.

Figure 2 shows the three measurements of the mean longitudinal magnetic field of the Ap star HD 142070 that we obtained from consideration of its whole spectrum, together with the measurements of Mathys et al. (in preparation), based on CASPEC spectropolarimetric observations. The good agreement between the two datasets confirms the quality of the longitudinal field determinations achieved from

FORS 2 observations and indicates that the order of magnitude of their quoted uncertainties is correct.

3 Discussion

In no star do our measurements reveal the presence of 1–2 kG fields. Our ability to detect weaker fields is limited by the accuracy of the measurements, as a result of the faintness of the studied stars and of the readout mode that was used. In only one case, SB 290, the longitudinal field determined at one of three epochs is formally significant at a level greater than 3σ . For this star, the reduced χ^2 of the three measurements that were performed also supports the reality of a detection at a confidence level greater than 99%. However, this conclusion depends critically on the correctness of the adopted measurement uncertainty; if the latter was only slightly underestimated (by 20% for the measurements based on all absorption lines), it would be invalidated. Thus measurements at more epochs and with better accuracy are needed to confirm the presence of a magnetic field in SB 290.

On the other hand, no significant longitudinal field was detected in Feige 86 in our recent spectropolarimetric observations of May 2011. The measurements resulted in $\langle B_z \rangle_{\text{all}} = 55 \pm 49$ G.

In conclusion, this study shows that large-scale organised magnetic fields of kG order are not generally present in sdB stars with $T_{\text{eff}} < 30\,000$ K. Yet it leaves open the possibility that these stars may have fields of a few hundred Gauss, with in particular a tantalising, although marginal, detection in one of them, SB 290. A firmer conclusion will require additional observations of higher quality.

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